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Research Article

Geology and Structural Evolution of Neoproterozoic Rocks of Guliso Area, Wollega Western Ethiopia

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ABSTRACT

The research was conducted in the Guliso area, to study the petrography, metamorphism, structures and to construct a detailed geologic map of the area. The focused area was manifesting the sequences of eastern high-grade gneisses, central metamafic-ultramafic, and western low-grade metavolcanic-sedimentary rocks. The systematic field works and petrographic studies were used to detail identifications of the lithology and mineral assemblages that constitute the rocks of the area. Guliso area is characterized by high-grade gneiss, serpentinite-dunite, talc-chlorite schist, and granitic and gabbroic intrusions. Petrographic properties of the metasedimentary, metavolcanic, metaultramafic, gneiss, and migmatite gneiss rocks of the Guliso area suggested that these rocks have undergone low-grade to high-grade metamorphism up to greenschist facies. Whereas the abundance of mineral assemblages such as hornblende, amphibole, and biotite in gneiss and migmatite gneiss indicate that the rocks of the area also underwent high-grade metamorphism of amphibolite facies. The findings were also proposed three phases of deformations which is correlated with the previous classification, and all geological resources related to the geology of the area were indicated the good potential of metallic, industrial minerals, and construction materials.

Keywords: Guliso; Metamorphism; Deformation; Neoproterozoic; Geologic structures

INTRODUCTION

East African Orogeny formed during the Neoproterozoic subduction of the Mozambique Ocean, which separated from India to the African continent, and was deformed and amalgamated during the late Neoproterozoic-Cambrian assembly of Gondwana [1,2]. It encompasses the Arabian–Nubian Shield in the north and the Mozambique Belt in the south [3]. The Arabian Nubian Shield is dominated by low-grade volcano-sedimentary rocks with the association of plutons and ophiolitic remnants [2-9]. The Mozambique Belt (MB), which is a tract of largely older continental crust that was deformed and metamorphosed during the Neoproterozoic contains poly-deformed high-grade metamorphic assemblages, that exposing middle to lower crustal levels [2,10-13]. Tefera described the Precambrian basement of Ethiopia as one of the basements found in East African Orogeny in which its exposures are found in the areas not intensively affected by Cenozoic volcanism and rifting and where the Phanerozoic cover rocks have been eroded [14]. This Precambrian rock of Ethiopia lies between the predominantly gneissic rocks of the Mozambique Belt, to the south and the Arabian Nubian shield to the north [15]. It is exposed in the northern, southern, eastern, and western parts of Ethiopia. The Precambrian of Western Ethiopia consists of high-grade gneiss and migmatite in the east and west and low-grade Meta volcano-sedimentary rocks at the Centre which are bounded on either side by two parallel NNW-SSW trending Tulu Dimtu and Asosa-Kurmuk ophiolite belt [16]. This belt disappears to the north and south under Cenozoic cover, but the ophiolitic zone has been correlated with the Barka or Baraka Suture of NW Eritrea [17,6]. Even though several studies have been conducted on the western Ethiopian basement complex, the Guliso area is less documented in terms of metamorphism and structural evolution. Therefore, this study presents the detailed petrography, metamorphism, and deformation events of the Guliso area using field observation, lithological identification, petrographic description, and structural data analysis.

Geological setting

Ethiopian basement comprises a variety of metavolcanic-sedimentary and plutonic rocks (Figure 1) metamorphosed to varying degrees from greenschist to amphibolite-facies and locally granulite-facies condition [18,19]. Precambrian rocks of Ethiopia are classified into three main complexes: The Lower, the Middle,

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and the Upper Complexes [18,20]. The lower complex includes various high-grade gneisses and migmatites found in the south and southwest (Konso, Alghe, Awata, and Yavelo gneisses). While the middle complex is represented by rocks such as psammitic and politic metasediments (biotite and quartz-muscovite schists, meta-arkoses, quartzite) with subordinate marbles, calc-silicates, and amphibole schists which have been exposed in Sidamo, Hareghe, and Western Ethiopia [20]. The upper complex is composed of low-grade rocks such as amphibolite, chlorite-actinolite schist, metavolcanics, graphitic schist, phyllite, metasandstone, and meta conglomerate [19,21-23]. According to Kazmin, the lower complex is Archaean in age [20]. However, based on the recent geo-chronological, thermo-barometry, geochemical and lithotectonic data, this classification of three stratigraphic units is oversimplified and the maximum age is constrained from pre-and syn-tectonic intrusive rocks are not more than 1100 ma [19].

Litho-stratigraphy of Western Ethiopian shield

The Precambrian geology of western Ethiopian terrain consists of volcano-sedimentary terrain, gneissic terranes, and ophiolitic rocks which are similar to Neoproterozoic rocks of the ANS and rocks of the MB [20,24-27]. The lithological components found in this region include; high-grade rocks; ophiolite belt; dioritic (granodioritic) batholiths and associated intermediate volcanic; and metavolcanic-sedimentary rocks [20,24]. The Precambrian basement of Western Ethiopia extending northward from 60 N for about 650 km is the largest Precambrian block in Ethiopia [16]. According to Kazmin geology of western Ethiopia Precambrian terrain is considered to contain lithological components common to both the Arabian-Nubian Shield (ANS) in the north and the Mozambique Belt in the south [24,28]. This study classified the geology of the area into five tectonic zones: (1) an eastern block of high-grade pre-Pan-African rocks; (2) an ophiolite belt; (3) a zone of dioritic/granodioritic batholiths and associated intermediate volcanic; (4) a metavolcanic sedimentary belt; and (5) a western block of the high-grade pre-Pan-African basement. This western Ethiopia in the Gimbi-Asosa area, the Tulu Dimtu Belt consists of a variety of moderate to high-grade gneisses and low to moderate grade metasedimentary rocks intruded by deformed and undeformed ultramafic, mafic, intermediate, and felsic igneous bodies [7].

Structural evolution of Western Ethiopian shield

Tulu Dimtu Belt (TDB) is exposed in the west Ethiopian shield as an NNE- trending fold and thrust belt at western Ethiopia shield [7,16]. The structural evolution of WES (Tulu Dimtu Belt) is being presented by D1–D3, which is applied only to the volcano-sedimentary units, and represented the Pan African deformation sequence, but most of the ductile deformation recorded in the gneiss domains is of pre-Pan African age and that the Pan African imprint may be represented only by the very latest ductile and brittle deformation phases [7]. The southwest of western Ethiopian Shield along Gore-Gambella district recorded four regional deformation events D1-D4 [27]. The first deformation event, D1 (Figure 2A), resulted in the formation of a sub-horizontal gneissosity within the gneissic terranes that were subsequently folded by D2 (Figure 2B). D2 (E-W shortening) is present in all domains, formed following east-west shortening of the region [27]. This deformational event is ubiquitous throughout WES. Mylonite, the result of intense D3 shearing (Figure 2C), occurs throughout the Birbir domain. The Birbir shear zone, which is NNE-striking, is one example of a D3 deformational event. D4 occurred much later (post-Pan-African) and resulted in the formation of large northwest-southeast oriented brittle structures [27].

METHODOLOGY

An integrated approach of field mapping, petrographic characterization, and structural analysis was used to constrain the geology and structural evolution of the Neoproterozoic rocks of the Guliso area. Accordingly, fifty (50) representative outcrop samples from all lithologic units have been collected. Among the collected samples, thirty-five (35) representative rock samples were selected and sent to the Geological Survey of Ethiopia for thin section preparation. The prepared thin section was studied using a petrographic microscope at the Department of Geology, Wollega University. Structural measurements of foliation have been collected during fieldwork. These structural data were analyzed using stereonets software.

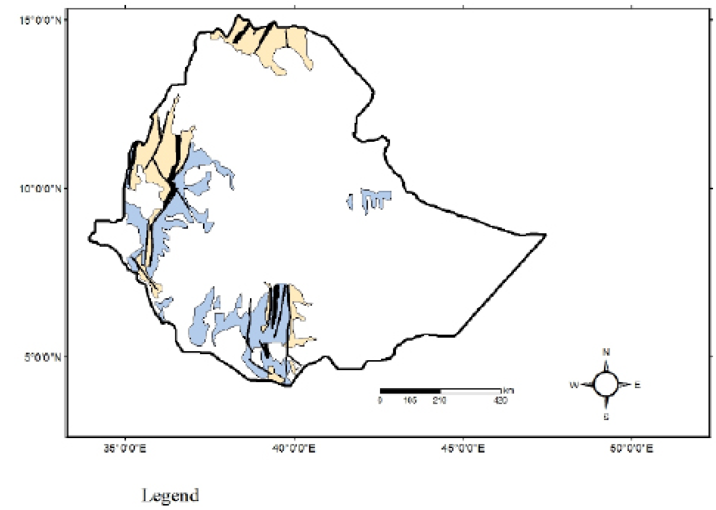

Figure 1: Distribution of the neoproterozoic Pan-African belts (ANS and MB) and reworked pre-neoproterozoic crust in Ethiopia [19]. **Note:** ( )Mafic-ultramafic belts; ( ) Low-grade volcanosedimentary rocks and associated intrusives; ( ) High-grade gneisses and migmatites with associated intrusives; (—) Precambrian faults and shear zones.

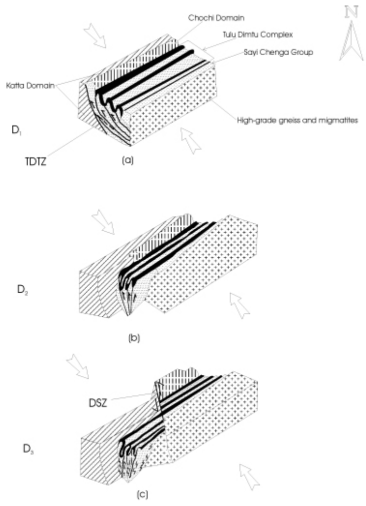

Figure 2: Structural evolution of Pan African Tulu Dimtu Belt according to Alemu and Abebe, A) early deformation (D1), TDTZ (Tulu Dimtu thrust fault/ shear zone), B) D2 deformation, which is resulted in deforming the initially sub-horizontal, D1structures about more upright folds, C) D3 represent extensive shortening, which resulted in formation of N- and NNE- trending ductile shear zone and NW sinistral Didessa shear zone (DSZ) [16].

RESULTS

Geology of Guliso area

Guliso area is underlain by three major rock groups: Meta volcanic rocks, meta-sedimentary, and meta-ultramafic rocks (Figure 3) intruded by plutonic rocks like granite and gabbro. The meta-sedimentary group consists of meta-pelite and meta-psammite which occupy most of the Guliso area. While remaining parts of the study area are covered by meta-ultramafic rock (consisting of Serpentinized dunite and talc schist). The Plutonic rocks include granite, granodiorite and gabbro. During field observation and mapping around the Guliso area, Granite gneiss, talc-graphite schist, Serpentinized dunite, and gabbro are the major rock units that were identified as their textural fabric and mineralogical compositions and mapped (Figure 3).

Gneiss: Based on the intensity of deformations; two varieties of gneiss were exposed in the study area. These are poly-deformed (Figure 4A) and weakly deformed (Figure 4B) gneiss. This rock is weakly to strongly gneissose, and the gneissosity being defined by the segregation of elongated felsic minerals on the one hand, and mafic minerals like biotite and hornblende on the other (Figures 4D and 4F). The unit is composed of various proportions of biotite gneiss, biotite hornblende gneiss, quartzo-felspathic gneiss and amphibolites gneiss. Among this biotite gneiss is the common one. Microscopic investigation indicates that the rock is composed of 30% Quartz, 25%alkali feldspar, 15% biotite, 10% plagioclase, 7%hornblende, and 3% muscovite. The thin sections prepared from this rock show strongly foliation defined by quartz, biotite, alkali feldspar, and muscovite (Figures 4C-F). Granoblastic, lepidoblastic and lepido-nematoblastic textures are common in the thin section (Figures 4C and 4E).

Metapelite: Interbedded meta-pelite and meta-psammite represent stratigraphically the youngest part of the Tulu Dimtu complex which is exposed mostly at the Guliso area [16]. The meta-pelite exposed in the study area includes graphitic slate (Figure 5A), talc graphitic schist, and weathered slate (Figure 5B). They show strong foliation and are characterized by fine grain texture. Most of the outcrops of these rock units were highly affected by weathering. The major mineral constituent of the meta pelitic rock unit is 35% biotite, 30% opaque (graphite), 20% quartz, 10% muscovite, and 2% plagioclase. The dominant matrix minerals are biotite, muscovite, and quartz (Figures 5C and 5D).

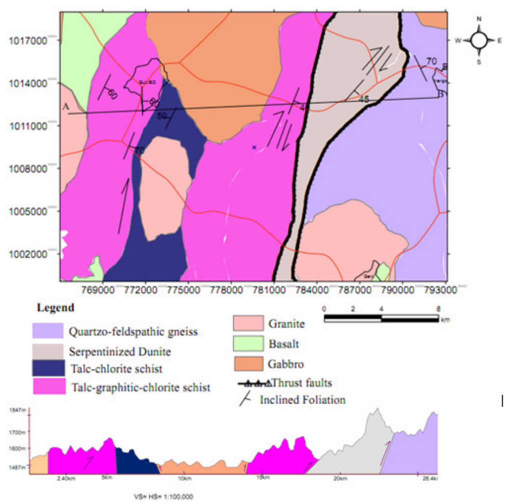

Figure 3: Geologic map of Guliso area.

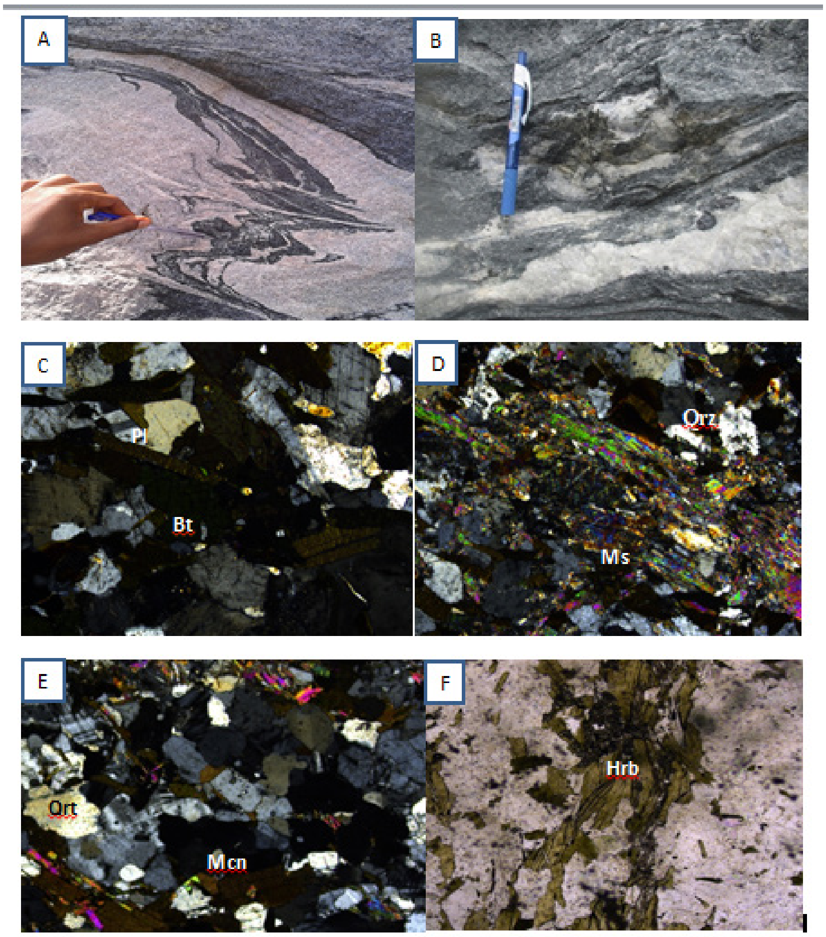

Figure 4: Exposure photograph of: (A) quartzo-feldspathic gneiss showing poly-deformed mafic and felsic mineral; (B) Quartzo-feldsphatic gneiss showing weakly deformed and segregation of mafic minerals from felsic minerals; and microphotograph of: (C) elongated biotite within subhedral to anhedral quartz; (D) segregation of elongated muscovite from quartz; E) anhedral Plageoclase and alkaline feldspar minerals with anhedral quartz; and (F) Strongly foliated Hornblende gneiss under PPL petrographic microscope.

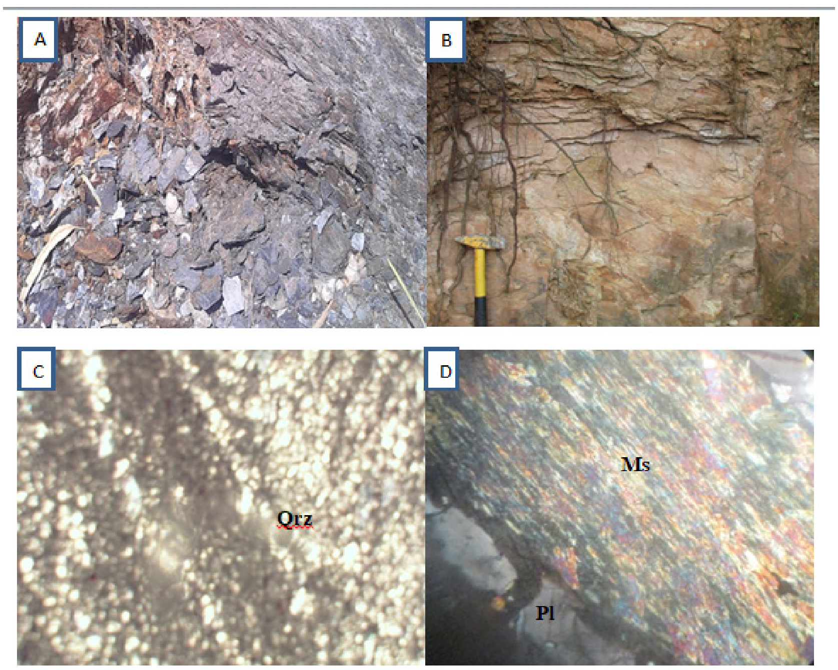

Figure 5: Exposure photograph of metapelite: (A) massive graphite schist; (B) weathered talc graphite schist; C) Well aligned quartz grain and (D) parallel alignment of mica in this thin section.

Serpentinite: The Serpentinite dunite unit is largely exposed at the eastern part of the Guliso town around the Dalati area along with road cuts and quarry sites. It is characterized by dark green color, to brown when weathered, weakly foliated, fibrous, and fine to medium-grained (Figures 6A and 6B). This unit is the common rock type forming the core and massive parts of the ultramafic bodies of the Tuludimtu Belt. Microscopic investigation indicates that the modal mineral composition of this rock is composed of 75% serpentine, 15% magnesite, 7% opaque (ilmenite or magnetite), and 3% chlorite (Figures 6C and 6D). Highly altered magnesite and serpentine are common in these rock-thin sections.

Talc schist: The talc schist unit is the smallest compared to other units exposed in the study area. This unit is exposed in the eastern part of the area (Figure 7A). The talc schist unit is characterized by strong foliation, brown to whitish color, fine-grained and schistose texture. The foliations of this unit are mostly striking 025˚to 045˚and steeply to vertical dipping 70˚to 90˚SE. From the petrographic analysis the talc schist unit is composed of 80% talc, 5% magnesite, 10% actinolite, and 5%opaque (Figure 7B). Talc, magnesite, and opaque minerals show well-developed parallel alignment and they define strong foliation and schistose texture (Figure 7B).

Granite: Granite is the largest portion of the intrusion in the study area and is characterized by light-colored, very coarse-grained texture (Figures 8A and 8B). It forms hills and ridges and outcrops as big rounded blocks. The intrusions form circular and elliptical shapes. It is typically biotite granite and at places shows the presence of pegmatite bodies. Compositionally, this granite consists of variable size Na-rich plagioclase, K-feldspar, quartz, muscovite, and biotite. This unit is made up of medium to coarse-grained, massive, pink to grayish pink, and leucocratic granitic rocks. Microscopic investigation indicates that the rock is composed of 50% quartz, 25% alkali Feldspar (mostly microcline), 7% opaque (ilmenite or magnetite), and 3% biotite (Figures 8C and 8F). Plagioclase shows alteration to sericite mica in some thin sections.

Gabbro: This rock unit is also one of the mafic intrusive rocks exposed in the Guliso area. This intrusion is a fresh and un-metamorphosed rock unit (Figure 9A). It is medium to coarse-grained mesocratic to leucocratic and exhibits typical banding where plagioclase and amphibole make up the light and dark bands. The marginal zone consists of melanocratic gabbro, which is generally fine-grained, but coarsens towards the interior of the intrusion and exhibits hypidiomorphic texture. The intrusion was from an elliptical shape. Thin sections study revealed that the rock is composed of 35% plagioclase, 30% pyroxene, 25% amphibole (actinolite), 5% opaque and 3% sphene (Figure 9B).

Basalt: The exposures of this unit are exposed in the Guliso area to the west part around Gute Mountain. It is the most extensively exposed of all the volcanic rocks in the area (Figure 10A). It covers an area of about 5 km2. This unit was gradually overlaying the post-tectonic granite, and other crystalline basement rocks and forms hills and ridges in the area. Most of the samples from this unit are fine-grained with few porphyritic varieties, containing clinopyroxene, olivine, and plagioclase. Average modal estimation of the essential minerals indicates that plagioclase makes the greatest part of the rocks, which is about 30%. The remaining part is constituted by; olivine about 15%, pyroxene about 10%, rare nepheline, and sodicfoid minerals (Figure 10B).

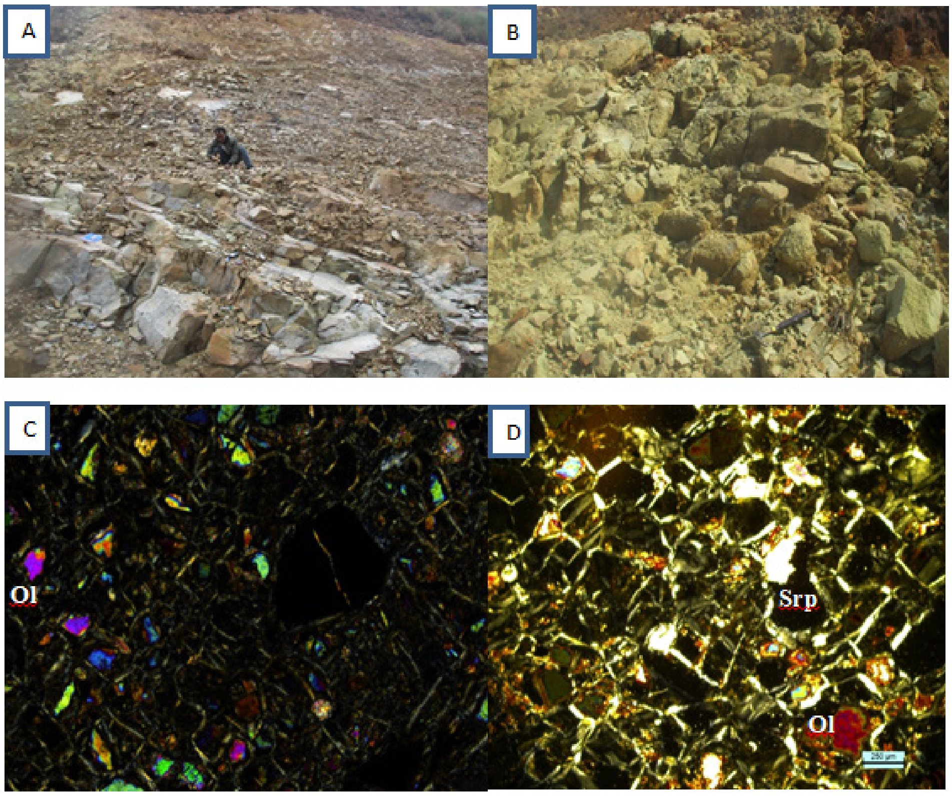

Figure 6: A) Exposure photograph of massive serpentinite dunite outcrops; B) Weathered serpentinite exposed along road cut; (C, D) Microphotographs showing mesh textures of serpentine grains in this field of view.

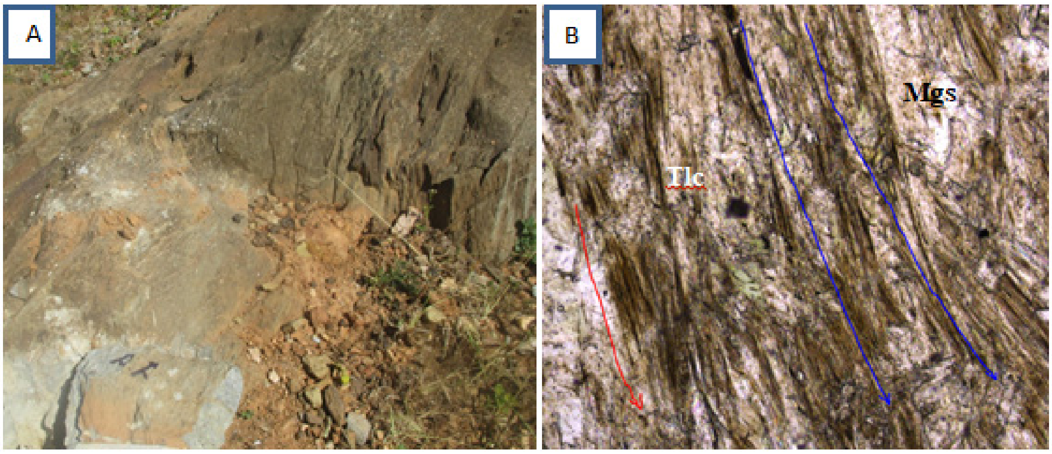

Figure 7: A) Exposure photograph of talc schist unit; B) Microphotographs of talc schist showing parallel alignment of minerals (foliation) which displaying schistose texture.

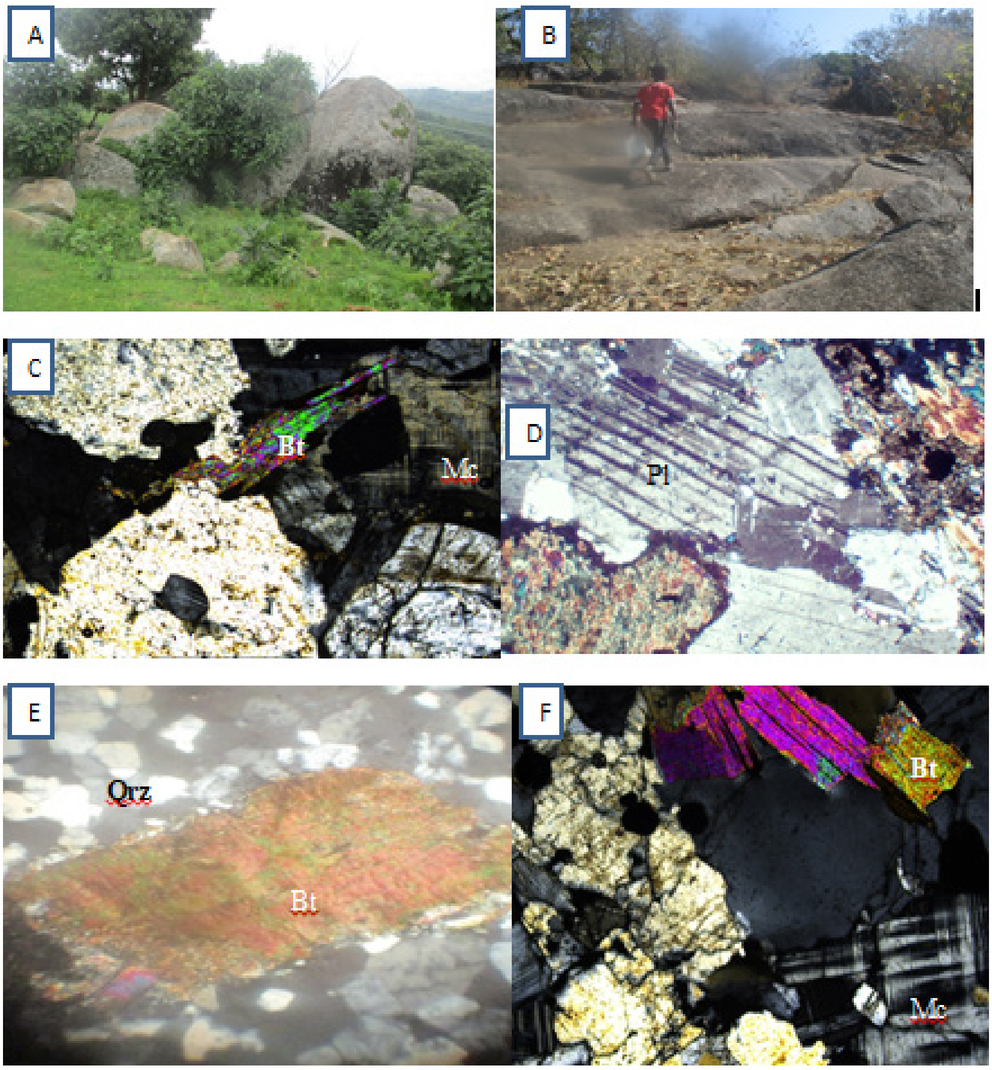

Figure 8: A) Boulder granite out crop, B) Exposure photograph of massive granite, C) Microphotographs of granite showing anhedral quartz and Plageoclase, D) Plageoclase alteration to sericite, E) Biotite overprint on quartz, F) Across hatching of microcline in granite.

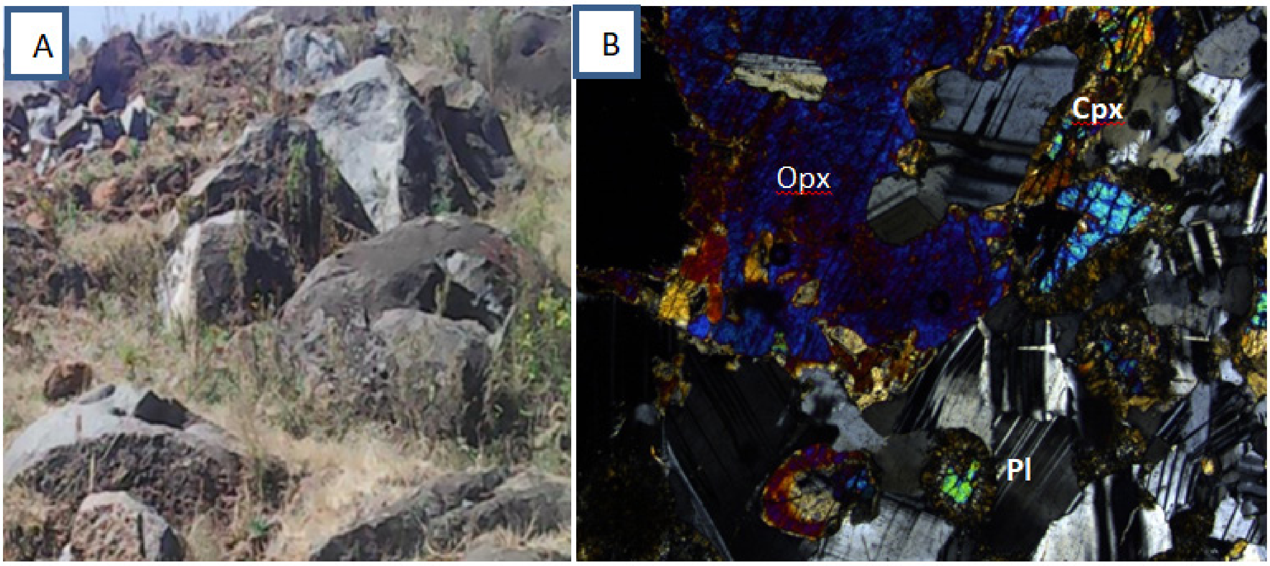

Figure 9: A) Field photograph of boulder gabbroic rock, B) Microphotographs of gabbro showing anhedral shape of plagioclase and orthopyroxene crystal.

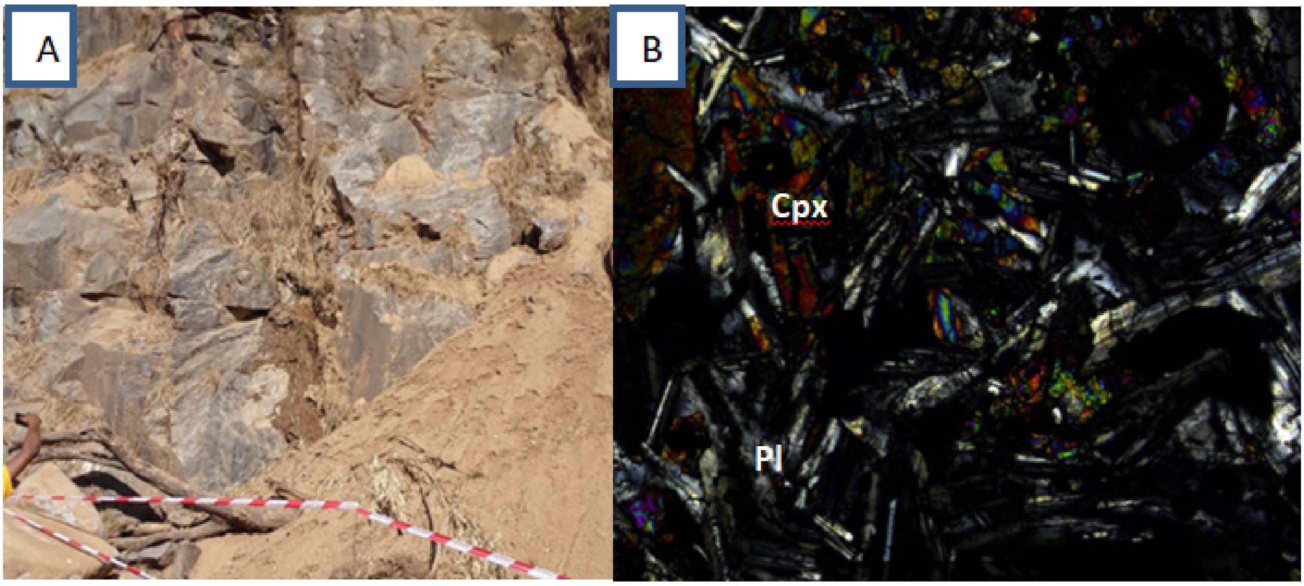

Figure 10: A) Field photograph of basaltic rock, B) Microphotographs of basalt showing sub-hedral shape of plagioclase grains.

Geological structures of Guliso area

The rocks of the Guliso area have been affected by several phases of deformation as evidenced by both ductile and brittle structures in the area. The ductile structures include foliation and lineation while the brittle structures include joints, veins, and fractures. Although their distribution is different throughout the area, the ductile structure is mainly observed in metasedimentary rocks while the brittle structures are common in metavolcanic, metaultramafic, and metasedimentary rocks. It has been observed during fieldwork that the intensity of deformation and structural complexity decreases from the eastern to the western part of the Guliso area. Fieldwork and petrographic analysis revealed that the rocks of Guliso under gone poly-phased deformation and three phases of deformation were recorded. The first phase of deformation (D1) and second phase of deformation (D2) are mostly attributed to the ductile deformational phases while the post-D2 deformational phase called (the third phase of deformation (D3) is attributed to the brittle deformational phase during which the veins and joints were developed.

1. Foliations (S1): S1 foliation is the most common structure, which affected most of the rocks of the area. In the Guliso area, this foliation is defined by slaty cleavage and alignment of elongate minerals (Figures 11A and 11B). Spaced and continuous cleavages are the most common S1 foliations in the Guliso area. Foliation (S1) in the area is mostly striking NE to SE with gently to vertical dipping WNW and SE as shown in the stereographic projection (Figures 12A and 12D). Most of the time the (S1) foliation in this area was parallel to the axial plane of F1 folding in the area.

2. Fold: The fold is the most common structure in the metamorphic rocks of the Guliso area. During the field investigation, different types of mesoscopic F1 folds were identified in the gneiss outcrops. These mesoscopic folds range in size from centimeters to very few meters (Figure 13). The axial planes of these folds are parallel to the S1 foliation of the area (parallel to regional foliation).

3. Shear zones: Shear zones are trending mainly N and NE and vary in width from few meters to kilometers and can be traced for the entire length in the belt. These shear zones bounded different lithologies in the belt and the boundary between the belt and the adjacent lithotectonic domains. The kinematic indicator within the shear zones likes; rotated porphyroclasts, steeply plunging S-folds, and S-C bands indicating the sinistral sense of movements especially in the high-grade rocks (Figures 14A, 14C and 14D).

4. Joint: Joint is another common brittle structural feature identified in the metamorphic rocks of Guliso with a variable in opening style and geometry (Figures 15A and 15B). Joints of the area were mostly trending N, NE, and SE with sub-vertical to vertical dipping. It is formed as a result of later deformation. Some of the joints and fractures are filled by quartz or calcite veins as observed in the field and petrographic investigation.

5. Vein: Veins are obtained and identified during the fieldwork and from the petrographic analysis. The most common veins in the study area were quartz veins (Figure 16). This vein type is obtained in the meta-sedimentary and plutonic rocks of the study area as the mesoscopic or microscopic scale.

Figure 11: Field photograph showing: A) strongly foliation defined by mica and feldspar, B) The foliation is defined by slaty cleavage.

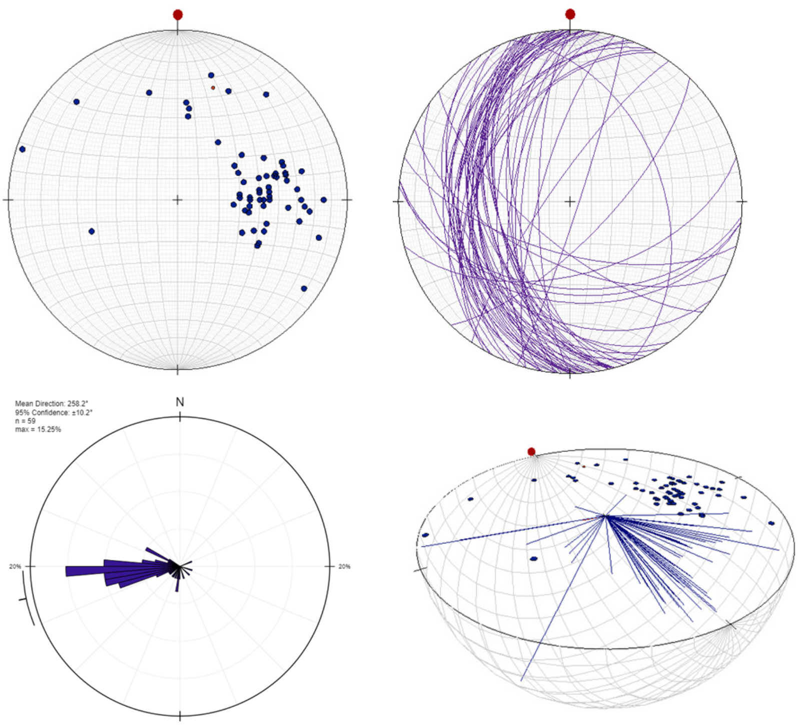

Figure 12: Figure showing: A) Lower hemispher equal area stereonet plot of poles to S1 foliation from Guliso formation (no=59), B) Lower hemispher equal area stereonet plot of plane to S1 foliation from Guliso formation (no=59), C) Rose chart of equal area stereonet of S1 foliation (no=59), D) 3D View of Equal area stereonet of S1 foliation (no=59).

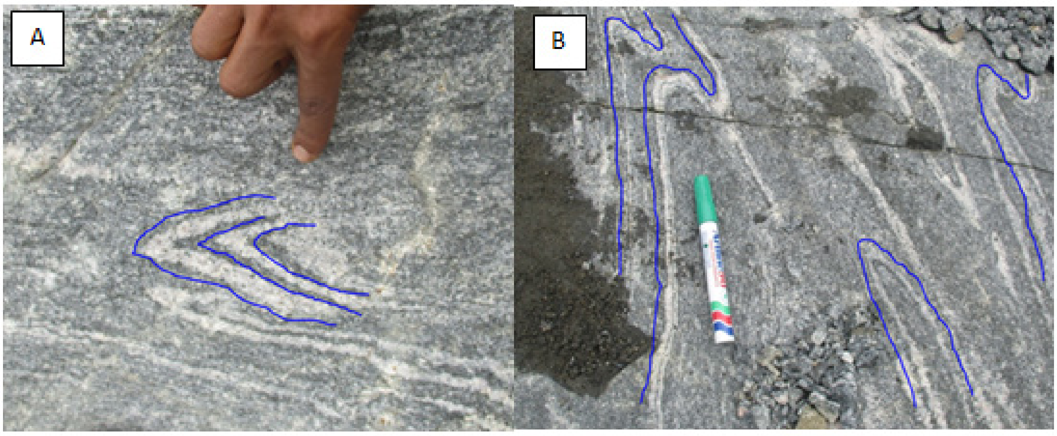

Figure 13: Field photograph showing: A&B) Folded felsic minerals in the quartzo-feldsphatic and biotite gneiss.

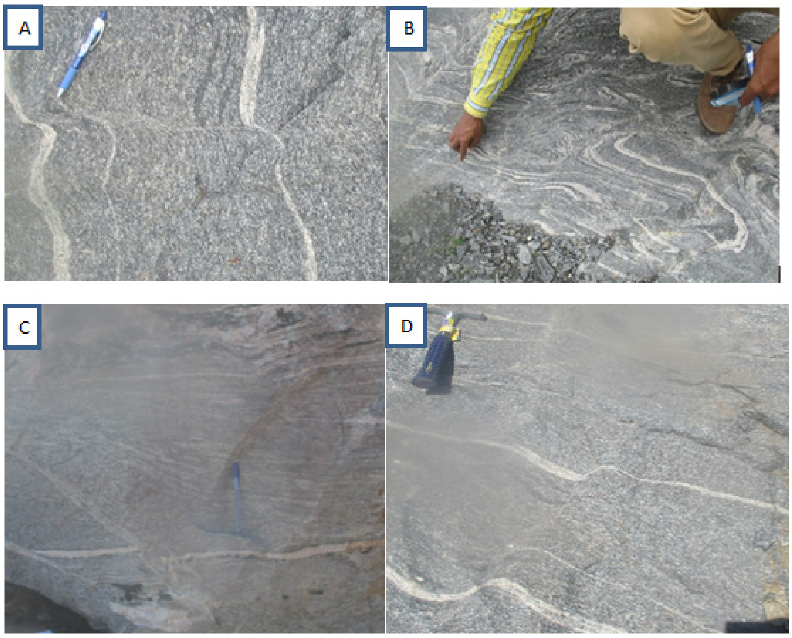

Figure 14: Field photograph showing: A, B &D) Ductile shear zone, C) Ductile-brittle shear zone.

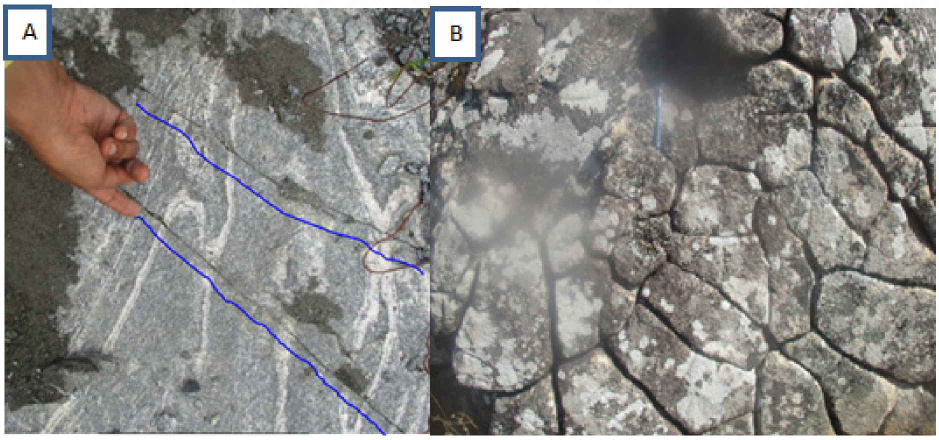

Figure 15: Field photograph showing: A) Regular joint space on the gneiss unit, B) Joint on the granite outcrops.

Figure 16: Field photograph showing: A) Folded quartz vein in the granite gneiss, B) Quartz vein in the quartzo-feldspathic gneiss.

DISCUSSION

In the Gimbi-Assosa area, the Tuludimtu Belt consists of a variety of moderate to high-grade gneisses and low to moderate grade metasedimentary rocks intruded by deformed and undeformed ultramafic, mafic, intermediate, and felsic igneous bodie [7]. These sequences are invaded by pre-, syn- and post kinematic intrusions of peridotite–gabbro–diorite– granitoid composition [7]. The Guliso area is within the center of the Tulu Dimtu Belt and is composed of gneiss, talc schist, serpentinite, granite, granodiorite, gabbro, and basalt. Field study and petrographic analysis revealed that most of the rocks in the study area were highly metamorphosed. Evidence of metamorphisms such as textural, grain size, and alteration in the rocks of the area were recorded with relict of some minerals from the pre-existing rock types (Figures 4E,F; 5C,D; 6D; 7B). The metasedimentary rocks are composed of mineral assemblages such as chlorite, mica, sericite, quartz, and feldspar which shows their origin may be coming from pelitic rocks or clay-rich rock materials (Figures 5A and 5B). The presence of such mineral assemblages in the metasedimentary rocks of the study area indicates that the area was affected by low-grade metamorphism of greenschist facies.

Additionally, the abundance of mineral assemblages such as quartz, sericitized plagioclase, chlorite, epidote, actinolite, feldspar, opaque, calcite, talc, and some relict of pyroxene and olivine in metaultramafic rocks (Figures 6A and 6B) indicate that the area is experienced low-grade greenschist facies metamorphism. Whereas the abundance of mineral assemblages such as hornblende, amphibole, and biotite in gneiss and migmatitic gneiss indicate that the rocks of the area undergo high grades of metamorphism.

Tectonic evolution of the Neoproterozoic rocks of western Ethiopia suggests E–W shortening resulted in the collision of the East and West-Gondwana [3,6]. Collision may have followed the consumption of back-arc basins between arc terranes, now represented by deformed mafic-ultramafic sutures zone along the domain boundaries of the area [25-30]. The geometrical relationship between D1, D2 and D3 in the Tulu Dimtu Belt favors the proposition in which The Tulu Dimtu Belt was developed due to oblique collision in response to NW-SE compression stress. The intensity of rocks affected by foliations is controlled by the type of the rock and the degree of metamorphism/deformation that occurred during their formation. These S1 foliations are mostly developed in the metasedimentary rock group mainly in the metapelite. The ductile shear zone is one of the ductile structures exposed in the Guliso area. It is obtained in the high-grade rocks of the area. NW-SE and E-W trending brittle-ductile strike-slip faults/shear zones that are superimposed at high-angle to the D1 and D2 structures characterize D3 deformation.

CONCLUSION

Based on the field observation coupled with petrographic studies, the following conclusion can be deduced from the Guliso area Neoproterozoic rocks:

a) Guliso area is underlain by meta-sedimentary and meta-ultramafic rock and metavolcanic rocks. The meta-sedimentary group consists of quartzite and meta-pelite. While the meta-ultramafic groups consist of serpentinite-dunite and talc schist units.

b) The Guliso area rocks were affected by deformation and metamorphism as depicted from textural change, grain size modification, and recrystallization with relict of some minerals from the pre-existing rock types.

c) The Guliso area is situated within a strongly sheared and NE-SW foliated, low-grade volcano-sedimentary belt that is intruded by mafic-ultramafic and granitic intrusives (talc-graphite schist, talc schist, serpentinite-dunite, metagabbro, and meta- granite).

d) The Guliso area intrusive bodies and their host metavolcanic-sedimentary rocks have been metamorphosed from lower greenschist facies (mineral assemblage: mica+sericite+chlorite+quartz+feldspar) to lower amphibolite facies (mineral assemblage: actinolite+hornblende + amphibole+biotite+epidote) grades.

e) The Guliso area is affected by three phases of deformation: The earlier deformation (D1) is responsible for the formations of slaty cleavage, continuous and spaced cleavage, and NNE-SSW trending regional foliations; D2 deformational phases are mostly responsible for the formations of crenulation cleavage and crenulation lineation. The post D2 deformational phase called D3 may attribute to the later brittle deformational phase like veins, joints, and faults.

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